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THE HELIUM DISTRIBUTION SYSTEM FOR THE LARGE COIL TEST FACILITY (LCTF)*

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Abstract

The helium distribution system of the Large Coil Test Facility is designed to establish and maintain the thermal environment of the toroidal array of superconducting magnets throughout the initial test and evaluation period of the test program.

The refrigeration and liquefaction requirements for the LCTF will be discussed including both the usual cooldown, lead cooling, thermal conduction and radiation and joule heating losses, and the unusual losses due to simulated nuclear heating, magnetic coupling losses due to the transient fields of the driving magnets, and pumping losses due to fluid resistance and pump inefficiency.

The flow system is designed with separate cooldown and steady-state flow systems, and to simultaneously circulate helium under steady-state conditions through coils cooled by boiling liquid or supercritical helium at ∿4.0 K and >2.5-atm pressure. Separate helium storage dewars are utilized for vapor cooling of the current leads to the magnets with the effluent gas being stored after compression in high pressure storage tanks. The flow diagram will be presented in simplified form to show the salient features of the cryogenic system.

Summary

To provide the necessary environment for the superconducting magnets to be tested in the Large Coil Program (LCP), a liquid helium facility (LCTF) is being designed. Provision is made for supplying 4.2 K liquid for pool boiling-cooled coils and also 4 K supercritical pressure helium for forced convection-cooled coils. A separate supply of liquid is maintained for the helium-cooled electrical leads. A liquid nitrogen-helium heat exchanger is used during cooldown of the entire test assembly. Flexibility of operation is provided to permit testing of various combinations of coils at differing operating conditions.

Introduction

The use of high magnetic fields in future tokamak systems can be achieved with the use of superconducting magnets. The LCP, being carried out at the Oak Ridge National Laboratory in cooperation with industrial participants, is intended to show that large coils of the type that can be used in such a future reactor can be built and operated successfully; the program will ultimately test a cluster of six such coils up to a field strength of at least 8 T. To provide the necessary environment for this testing, a Large Coil Test Facility (LCTF) is being designed. One of the major systems required in the LCTF is the cryogenic helium system which will be described here.

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Design Philosophy

The design philosophy used took into account the several cooling functions that the system must perform and the programmatic functions imposed by funding limitations. The functions include cooldown and warm-up of the magnet coils and associated structure, heat removal from the coils and structure during operation including heat input by radiation, simulated nuclear heat, eddy currents, etc, supply of coolant for the current leads, and recovery and storage of helium during non-standard operational modes. The scheduling of program functions was imposed by incremental funding limitations which resulted in a phased program. The first phase is a single-coil pool-boiling test, so all system equipment required for pool boiling will likely be assembled for that test. The next phase, a three-coil test, will require additional equipment which, insofar as possible, will be prefabricated to minimize requirements for breaking into that portion of the LCTF already in use. Similarly, the next two phases, adding pulse coil capabilities and the final six coils, will use prefabricated components and be installed as add-ons to the existing facility.

Coil Cooling Subsystem

There are two methods being studied for the cooling of the large coils to maintain them at the appropriate superconductive temperatures: pool boiling of liquid helium and forced convection using cryogenic helium at supercritical pressures. Since at least one coil using each type of coolant is intended to be tested, it is necessary to provide a sufficient quantity of either one. The helium for the pool boiling loop will be stored in a 5000-gal (19,000 l) dewar which will be maintained at nominally 1.3 atm to supply the cryogen to the coils as saturated liquid at 4.2 K. Return vapor will be fed back to the helium refrigerator for reliquefaction.[1] Provision is made for supplying this liquid either at the top and/or the bottom of the coil as desired by the coil designer. Available cooling capacity has been specified at 250 W if the coil is the primary one being tested, or 50 W if the coil is being used in a background field mode.[2] Provision is made for up to five such coils to be supplied in nonsymmetric parallel loops and to return the total effluent vapor to the refrigerator.

The second cooling method, forced convection, requires the circulation of cryogenic supercritical pressure helium to one or more coils. The specification calls for 4 K, 6.0-atm supply and 6 K, 2.5-atm return conditions as the maximum allowable variations. The allowable refrigeration capacity is specified at 550 W for a test coil mode and 100 W when the coil is being used in a background field mode. Each of these conditions includes the thermal requirements for circulating pump power, which will be a function of the actual flow rate and pressure loss through the coil. To provide the required conditions, a dewar containing 3.5 K liquid is provided; its supply will be replenished from the refrigerator during operation. In the dewar will be located the circulating pump and two heat exchangers, one upstream and one downstream of the

These heat exchangers will be sized to remove the coil heat load and pump work, respectively, to provide the 4 K supply to the coil. The boiloff from the dewar will be returned to the refrigerator for reliquefaction. Other similar pump loops can be added if more than one coil of this type is to be used. It is intended to maintain the minimum pump loop pressure of 2.5-atm, and for the pump to supply whatever pressure is required up to 6-atm to overcome loop pressure losses.

Electrical Lead Cooling

The electrical leads for the coils will have a temperature gradient along their length from ~4 K at the coil interface to room temperature at the exterior end. At the cold end, helium will be boiled and the vapor will flow along the leads to remove the joule heating that will occur. A separate supply of liquid helium for the leads will be furnished to minimize effects of perturbations of other parts of the total system and to extend the capabilities of the refrigerator. Vapor effluent from the leads will return to the compressor, which is part of the helium refrigerator, and thus be recycled.

Helium Storage and Recovery

The storage and recovery system provides for accumulation of liquid or vapor during operation and recycling and also for capture of helium that might result from an incident in which relief valves or burst discs are caused to function. There are four 2000-gal (7500 l) warm helium storage tanks, three for storage of feed to the refrigerator compressor and one to accumulate vapor return from power leads and/or relief valve operation. A 5000 gal dewar receives liquid from the refrigerator at 1.3-atm and supplies feed to the pool boiling coils and the 2000-liter dewars for the electrical lead cooling. Ultimately, there will be three of these small dewars, one for each pair of coils in the six-coil array. Vapor boiloff from these dewars, as well as the 4.2 K vapor return from the pool boiling coils, returns to the refrigerator thru a cold expansion or surge tank. There are also small surge tanks on the forced-flow pump loops and the cooldown loops. In the event of a serious malfunction requiring burst disc activation, the effluent will be captured in a plastic "balloon" for later cleanup and recycling. The piping which leads to this emergency storage will provide sufficient heating so that the storage material will not become brittle and fail. Relief valves and burst discs will be provided at all locations that might trap liquid which, when vaporized could cause an over-pressure situation to occur.

Cooldown/Warmup Subsystem

The cooldown/warmup loop will provide the capability of bringing the entire test assembly to operating conditions, or of warming it back to room temperature when admission to the test equipment is required. The specification calls for cooldown from 300 K to 4 K to be accomplished in 120 hr and warmup to 300 K in 60 hr. The initial cooling will use liquid nitrogen (LN_2) as a heat sink. To preclude the possibility of subsequent freezing of nitrogen and the deleterious effects this might have, no LN_2 will flow in the coil or structure system cooling passages. Supercritical pressure helium will be used as a heat transfer fluid in these passages and will in turn be cooled in a LN_2-He heat exchanger. Circulation of the helium will be effected primarily with the refrigeration compressor, but an auxiliary pump/compressor will also be available. Since flow of the helium will take place in the available piping and cooling passages of the coils, it is expected that the most critical part of this process will be the cooling of the forced convection-cooled coils. This is due to the relatively long length and small flow cross-sectional area of these cooling passages. It is likely that additional channels may be required on the structural portions of these coils to permit the specified time for cooling to be met. Preliminary calculations have indicated that no serious problem of thermally induced stresses should occur during cooldown or warmup. The same basic equipment will be used for warmup but will employ heated nitrogen in the heat exchanger in place of the LN_2 used for cooling. Initially, one cooldown loop will be provided for the structure and up to three coils; second loop is planned when the six-coil testing begins later in the program.

Test Capabilities

From an operational standpoint, the major constraint on test time available is the refrigerator capacity. It is planned to use the output of the refrigerator to supply the 3.5 K dewar for the forced-flow loop during actual test operations and to supply 4.2 K liquid for the pool boilers and leads from the respective dewar storage. These will be replenished during test downtime, i.e., nights and weekends. From the data now available, it appears that approximately 40 hr of six-coil testing, five 8-hr shifts, can be reasonably used while filling storage the remainder of the week. For one- or three-coil tests, essentially continuous testing can be done if desired.

Thus far, the conceptual design of the LCTF has been completed, and the engineering and detail designs are commencing. These designs have been delayed until the requirements of the various coil designers have been established so that realistic line sizes, etc., can be determined. When the three contractors have supplied final reports on their designs, the work on the facility can continue. This facility will provide the proper thermal environment for testing of the six-coil array and should help acquire design information to permit the continued advancements in the fusion energy field.

References

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